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DISPLAY FACTORS AFFECTING THE VISIBILITY OF INFORMATION ON A SIMULATED PASSIVE SONAR DISPLAY

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ABSTRACT

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. This study examined the effect on signal detection of rotating a frequency-time-intensity (FTI) display 90 degrees so that the signal lines fell along the scan lines of the CRT. Currently, the signal lines on an FTI display are perpendicular to the CRT raster. The effect of having signal lines fall along the scan lines of the CRT was assessed on both a monochrome and a multichrome monitor to see if the effects were similar on both types of monitors. In addition, performance was assessed in two conditions in which the visual image was potentially degraded. The degraded displays resulted from the reduction in average luminance of the monitor that frequently happens over time and the use of long video cables between the computer monitor and processor. In all the conditions, subjects had to detect signals of varying strength presented on a simulated dynamic FTI display. Signals were added to a FTI display that was updated every 5 seconds. There was a clear advantage, on both types of monitors, to using a display format in which the signals fell along the scan lines of the CRT. Between 12 and 18% more signal lines were detected when the FTI display was rotated 90 degrees. Degradation of the output had no perceptible effect on detection of the signal lines. It was concluded that there is an advantage to designing the interface for a passive sonar display so that the signals fall along the scan lines of the CRT.

EXECUTIVE SUMMARY

With current sonar technology the operator must handle large quantities of data. The primary medium for displaying these data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. DCIEM was tasked to investigate two factors that were believed to influence the detection of signal lines on a frequency-time-intensity (FTI) display. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). Current sonar systems in the Canadian Forces use a single phosphor monitor because its resolution is believed to be superior to a multichrome monitor. However, there is considerable pressure to switch to a multichrome monitor for consistency with other computer-based systems and to take advantage of the benefits associated with colour coding. The second factor was the orientation of the signals relative to the orientation of the raster on the CRT. For consistency with paper FTI displays, frequency is plotted along the x axis and time along the y axis on a CRT. One consequence of this decision is that the signals are perpendicular to the scan lines of a CRT. It would seem useful to capitalize on the inherent line structure in the CRT when presenting images, such as an FTI display, that contain line patterns that are predominantly in one direction.

A previous study under this tasking found that detection performance was similar on a multichrome and monochrome monitor when a standard format FTI display was used and that signal detection improved somewhat when the FTI display on a monochrome monitor was rotated 90 degrees so that the signal lines fell along the scan lines of the CRT. The current study examined whether the benefit of rotating the display would be found with a multichrome monitor as well. Subject were required to detect signal lines of varying strength on either a standard format FTI display or on a modified display in which time appeared along the x axis and frequency along the y axis. In both cases, a simulated dynamic FTI display was used in which signal lines were added to the bottom (side in the rotated format) of the display at regular intervals, moved slowly up (across) the display, and disappeared off the top (other side) as they would in an operational system. A dynamic FTI display was used because it was thought that it would provide a more realistic assessment of the usefulness of having the signal lines fall along the scan lines of the CRT.

In addition, performance was assessed in two conditions in which the visual image was potentially degraded. The degraded displays resulted from the reduction in average luminance of the monitor that frequently happens over time and the use of long video cables between the computer monitor and processor.

There was a clear advantage, on both types of monitors, to using a display format in which the signals fell along the scan lines of the CRT. Between 12 and 18% more signal lines were detected when the FTI display was rotated 90 degrees. Degradation of the output had no perceptible effect on detection of the signal lines with either of the display formats. It was concluded that there is an advantage to designing the interface for a passive sonar display so that the signals fall along the scan lines of the CRT and it was recommended that a field study be carried out to assess the impact of the rotated display on the performance of experienced operators.

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INTRODUCTION

Background

Improvements in signal processing algorithms and computing power have resulted in a large increase in the amount of information that can be extracted from passive sonar sensor systems. Different sectors of the ocean can be monitored separately and a wide range of frequency and temporal resolutions can be made available to the operator. The most common method for presenting passive sonar information visually is the frequency-time-intensity (FTI) display. The FTI display shows the output of 'x' narrow-band filters over 'y' previous time periods. The average energy in one of the x frequency bands (or bins) over one of the y time periods is shown by brightness (on an emissive display) or darkness on a paper display. Targets appear as series of variable intensity lines against a noisy background.

The primary medium for presenting passive sonar data is the electronic display, in particular the CRT. The electronic display provides flexibility in terms of how the information can be displayed at any point in time. A fundamental limitation, however, is that the amount of information that can be displayed simultaneously is limited by the size and resolution of the screen. To monitor all of the available information, the operator must scan multiple pages of data rapidly. Under such conditions, the visibility of signals is critical.

The requirement for good visibility of signals makes it important to understand the impact of display characteristics on detectability. DCIEM was tasked(1) to investigate two factors that were believed to influence the visibility of signal lines on the screen. The first of these was type of monitor - multichrome (multiple phosphors or guns) versus monochrome (single phosphor). The second was the orientation of the signals relative to the orientation of the raster on the CRT.

Currently, passive sonar systems in the CF use monochrome displays. However, there is considerable pressure to switch to multichrome displays for compatibility with other shipboard computer-based systems and to take advantage of any benefits arising from colour coding. Resistance to the use of multichrome monitors arises because of the possibility that signal lines might be less visible than on a monochrome monitor.

To present as much information as possible on the screen at one time, the largest number of pixels possible are addressed on a monitor used in a passive sonar display. Addressability is a function of the display controller and refers to the number of specific points or x,y coordinates on the screen that can be selected. Whether each of those points is visible depends on the resolution of the screen. Resolution is usually defined as the width of a spot or pixel on the CRT when its luminance falls to 50% of maximum(2). If resolution exceeds addressability, black lines will be visible between successive lines of pixels. As addressability exceeds resolution, it becomes increasingly difficult to discriminate two lines separated by a single line of pixels. Ideally, the resolution to addressability ratio (RAR) of CRTs should be one. This is usually achievable on monochrome CRTs.

With shadow-mask CRTs (the most commonly used multichrome CRT), resolution is limited by the pitch of the shadow mask (distance in millimetres between vertically adjacent mask-hole centres). Usually a resolution of 1.1 to 1.2 the mask pitch is adequate(2). This is lower than the resolution that can be achieved on a monochrome screen and the number of addressable points will have to be lower as well to achieve an RAR of one. Otherwise, one may not be able to discriminate pairs of lines separated by a single line of pixels on the multichrome screen. Reducing the number of pixels would reduce the amount of information that could be presented on the multichrome screen.

In the past, operators evaluating the CANTASS ADM with monochrome and multichrome monitors that had the same number of pixels have consistently preferred the monochrome monitor. However, a study by Volkov(3) concluded that detection of signals on an FTI display was not significantly better on a monochrome CRT than a multichrome of the same size. The addressability of his displays were 1024 lines by 1280 pixels and the shadow mask pitch was 0.32 mm. He compared detection of signals on a sonar display presented on a monochrome monitor with a green phosphor and a multichrome monitor using the green or red gun to display the data. There was a small but significant advantage for the monochrome monitor over the multichrome monitor using the green phosphor. This advantage was found primarily with signals that did not vary in frequency. When the frequency of the signals varied with time, there was no difference in detection performance. Moreover, there was no difference between the red phosphor on the multichrome monitor and the monochrome monitor.

The study by Volkov did not investigate systematically the detectability of two signals separated by a single line of pixels. It is important that an operator be able to discriminate a doublet from a single line signal. The presence of doublets can be indicative of a particular class of target. In other cases, two signals close together can indicate the presence of more than one target. In the latter case, one of the signals may be fainter than the other. If the stronger signal masks the fainter signal then the operator may fail to detect the second target. It is the detectability of these types of signals that one would expect to be affected when addressability exceeds resolution. As well, Volkov used only a single gun (red or green) to display the sonar data. Mapping signal intensity onto different red or green brightness levels may not be desirable. The main advantage of going to a multichrome monitor is to allow colour coding of information. The colour appearance of symbols will be modified if they are presented against a saturated colour background(4). To optimize colour discrimination, it is preferable to map signal intensity onto different grey levels.

Thus an experiment was carried out under the current tasking to see if detection of signals, especially line pairs, was impaired when they were presented on a multichrome monitor with intensity mapped onto different grey levels(5). The study used a static display mode in which subjects were presented with a series of FTI displays each of which contained 6 signals at various levels of visibility. The signal lines always extended the full length of the FTI display. Approximately 20% of the signals were line pairs, usually with the two members of the line pair at different intensities, and the remainder were single lines. No differences were found between the two types of monitors on any of the measures of performance including hit rate, false alarms, and response times.

A second experiment under the tasking(6) looked at classification of targets on the two types of monitors. For this experiment, subjects were required to classify targets on a simulated dynamic sonar display. Subjects were initially trained to associate names with specific patterns of lines. During testing, examples of the target set were presented at regular intervals using a dynamic rather than the static display mode employed in the detection study. In the dynamic mode, target lines, non-target lines, and the noise background were added to the display pixel by pixel, a line at a time at regular intervals. At the same time, the top line of pixels was removed and the remaining lines moved up to make room for the new line of pixels added to the bottom of each FTI display. Thus, targets appeared at the bottom of the display and moved up it, over time, gradually disappearing off the top as in an operational system. With the classification task, as with the detection task, no differences were found in the percentage of targets identified or in response time, either overall or as a function of time on task. Test sessions lasted 60 minutes. The results of this experiment supported the conclusion from the detection study that there was no disadvantage, from a performance perspective, to using a multichrome display for displaying passive sonar information.

The second factor that was investigated was display orientation. For consistency with paper FTI displays, frequency is plotted along the x axis and time along the y axis on the CRT. One consequence of this decision is that signal lines are perpendicular to the scan lines of a CRT. In a raster scanned CRT (the type used most often for sonar displays), the electron beam scans horizontally across the field, is deflected back at the end of the line, and scans across the next portion of the screen. This process is repeated until the entire screen has been scanned. The image on the screen is formed by turning on the electron beam the appropriate amount at prespecified points across the screen surface. It would seem useful to capitalize on this inherent line structure in the CRT when presenting images that contain line patterns that are predominantly in one direction. For example, contrast sensitivity assessment systems that present vertical sinewave patterns on a CRT usually use a monitor that has been rotated 90 degrees so that the grating patterns are parallel to the raster.

There are two possible ways of presenting the FTI display so that signals fall along the scan lines of the CRT. The simplest is to display frequency along the y axis and time along the x axis. However, this could necessitate retraining of the sonar operators. Although operators are trained to classify targets analytically, successful classification usually involves matching the pattern on the screen with an internal template that has been built up as a result of extensive experience with similar patterns(7). Changing the orientation of the FTI display could reduce the effectiveness of this pattern matching process in the short term. The second method would be to rotate the monitor so that the scan lines are vertical. Signals would fall along the scan lines when the the data are presented in the standard format on this rotated monitor.

To evaluate the impact of orientation, an experiment was carried out to compare detection when the FTI displays were presented in the standard format, when the time and frequency axes were reversed, and when the monitor was rotated so that the axes appeared in the standard format but the time axis was parallel to the scan lines(5). The detection task was the same as that used for assessing the effect of monitor type. A small but significant advantage was found for the formats in which the signal lines fell along the scan lines. The results indicated that having the signal lines fall along the scan lines improved their visibility. The detectability of signal lines near threshold (detected less than 50% of the time) was not improved. However, the signal level at which moderately detectable lines were seen decreased 1 dB. In addition, the fainter of the doublet lines were detected significantly better at all signal levels.

The effect of display orientation on classification performance was also examined using the classification task that had been used to study monitor type(6). Since no difference was found between the monitor-rotated and the display-rotated conditions in the detection study(5), only the display rotated format was compared with the standard format in the classification study. No significant differences were found between the two display formats.

studies were chosen so that luminance of each output level was at least a factor of two greater than the next lower level. Ambient illumination was kept low to avoid glare on the screen and the average luminance was chosen to be consistent with the ambient illumination. The monitors were calibrated at regular intervals to ensure that the luminance of the pixels remained constant over the duration of the experiment. In the operational environment, measurement of the output of the monitors is not carried out as part of routine maintenance. Over time, the output tends to drift - usually downward. This means that when a specific voltage is applied to a point on the monitor, the luminance output is less over time. To maintain the same luminance, one must increase the voltage input. During the course of our experiments it was necessary to increase the input voltages (by increasing the digital to analog conversion (DAC) values associated with the different pixels) two or three times because of a drop in the measured luminance of the monitor.

To assess the impact of this normal degradation of the monitor, a supplementary experiment was run to compare performance in the main experiment with performance on the same task but using the current luminance levels of the set of DAC values used at the beginning of our experiments. The two sets of luminance levels are shown in Table 1. The primary difference was that the average luminance was lower. Kingdom and Moulden(8) found no difference in performance with average luminances of 3.8 and 29 cd/m^2. Thus a small difference in average luminance in this experiment would not be expected to have an effect.

A second factor in the operational environment that can affect display quality is the use of long video cables because the monitor is located some distance from the processor. Consequently, the analog signal must travel over an extended distance. The impact is usually a somewhat defocused display and reduced contrast. To study the impact of a degraded video signal on detection performance, the standard video cables on the monochrome display were replaced with three 60 metres long cables.

Half of the subjects in the original experiment completed the low luminance condition and the other half completed the long cable condition. Each subject completed four runs in their assigned condition. In the low luminance study, two runs were carried out on each monitor. In the long cable condition, all four runs were carried out on the monochrome monitor.

METHOD

Subjects

A total of 12 observers, 9 males and 3 females, participated in the experiments. They ranged in age from 19 to 29 (mean = 24.4) and had normal or corrected-to-normal vision based on self-report, as well as a measure of visual acuity (Regan Chart) and a measure of contrast sensitivity (Nicolet CS2000 System). All subjects were naive to the task, but they were given a complete explanation of the study and the task before giving their consent. They were recruited from DCIEM and CFB Toronto personnel and from nearby universities and were compensated for their participation according to federal government guidelines.

Apparatus

The Sonar Display Simulation System was controlled with a Northern Micro personal computer with an 80486 processor and an ATI Graphics Ultra Pro video card. The simulation was displayed on either a 51 cm Nanao FlexScan T660i multichrome monitor or a 53 cm Nanao FlexScan 6500 greyscale monitor. For the long cable experiment, the standard video cable of approximately 1.7 metres in length, that connects the processor to the monitor, was replaced with three 60 metres long video cables.

The addressability of both monitors was set to 1024 pixels by 764 lines and the active area of the screen was equalized between the monitors such that each pixel had a nominal visual angle of 2.3 min. of arc at a viewing distance of approximately 53 cm. The x,y chromaticity coordinates were 0.352, 0.399 for the greyscale monitor and 0.341, 0.393 for the multichrome monitor[1] at a luminance of 32 cd/m^2. Interaction with the screen was carried out using a mouse and special function keys. Subjects used the mouse to position a cursor over a possible signal and then clicked the left button on the mouse to record their response. A function key was pressed to indicate the end of a trial where necessary.

The two monitors were characterized, using a Minolta Chroma Meter CS-100 colorimeter fixed to a tripod, by measuring the output at every fourth digital to analog (DAC) or voltage input level between 0 and 64 (the maximum DAC value). Each measurement was made on a block of pixels, at the specified DAC values, located in the center of the monitor. In the case of the multichrome monitor, the measurements were made with the identical DAC values applied to all three phosphors. Luminance was plotted as a function of DAC value and a curve fitted to the data. The curves were used to select the DAC values on each display that would produce the same luminances on each monitor. These luminance levels were checked at regular intervals throughout the experiment. If the monitors started to drift, they were characterized again and new DAC values were selected that would produce the original luminances.

Stimulus configuration

A schematic of the two stimulus configurations used in the experiment is shown in Figure 1. In the standard display conditions, frequency was displayed along the horizontal axis, time along the vertical axis, and intensity was mapped on to the luminance of the pixels, such that the more intense the energy in a given frequency-time bin the higher the pixel luminance. In the rotated display conditions, the axes for frequency and time were reversed. Each of the four bands in the displays spanned 620 pixels (22.5° of arc) by 112 pixels (4° of arc), with a 50 pixel separation between the bands. The dimensions of the total display were 21.6° of arc in height by 22.5° of arc in width at a distance of approximately 53 cm. The frequency range was 1200 Hz, with 0-155 Hz on the first band, 150-305 Hz on the second, 300-611 Hz on the third, and 576-1200 Hz on the fourth band. There was a small frequency overlap at the ends of the bands to facilitate the detection of signals that might appear in those areas. Along each band were scale markers (not shown on the schematic) placed at 25 Hz intervals on the two lower frequency bands and at 50 Hz intervals on the two higher frequency bands.

[1]These were the chromaticity coordinates for the multichrome screen when the same DAC (Digital to Analog Conversion) values were applied to each gun.

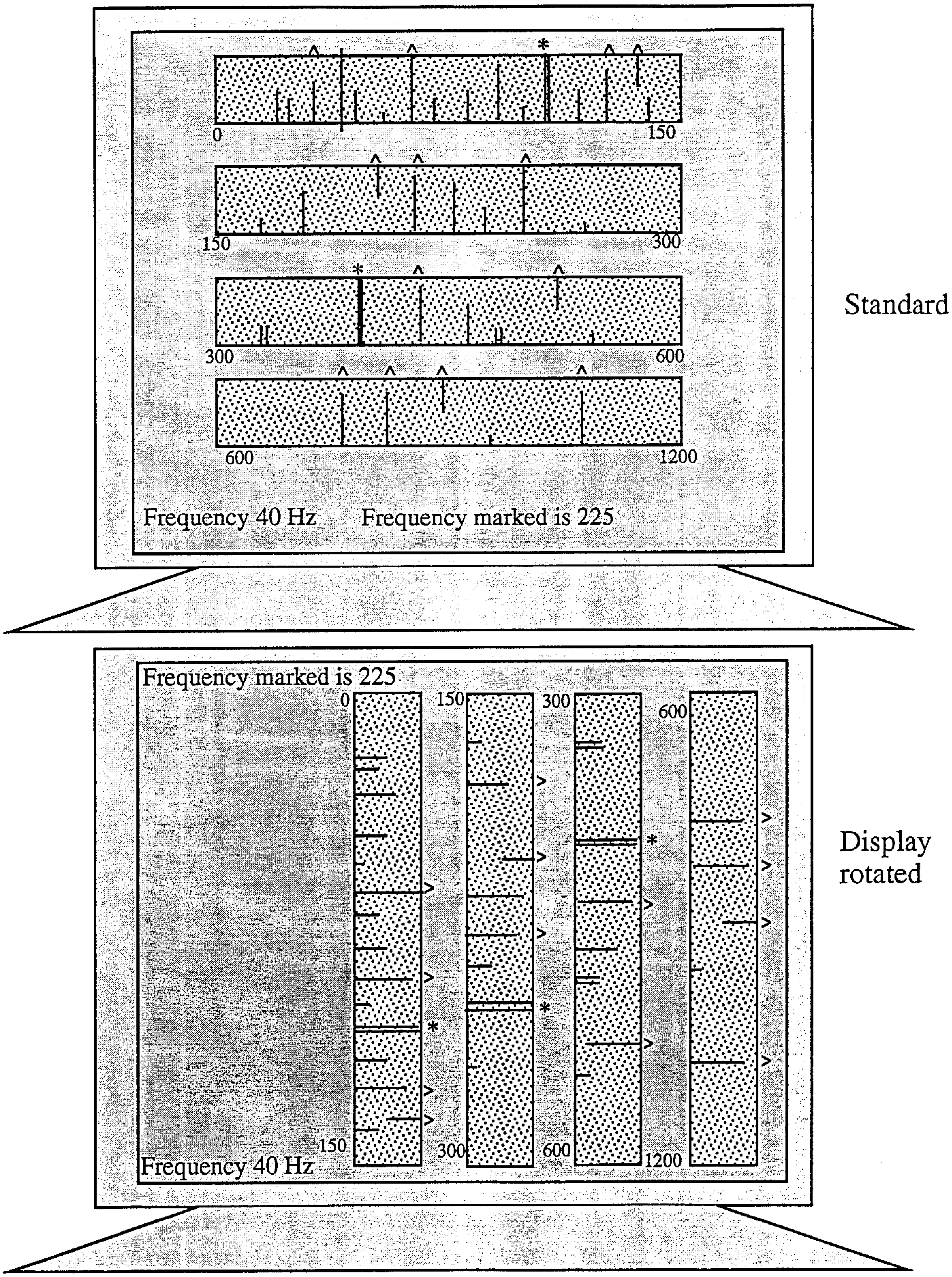

Figure 1: Schematic of the stimulus configuration for the standard and rotated formats on the monochrome and multichrome monitors for the dynamic detection task.

The signal lines and the cursor were presented as lines one pixel wide that replaced the background noise. The cursor was 120 pixels in length, so that it extended four pixels either side of a band. The alphanumerics were displayed at approximately 4 cd/m^2 and the cursor at approximately 11 cd/m^2.

The schematic shows the screen used in the dynamic mode. It was used for some of the training sessions and all of the test sessions. Initial training was carried out using a static mode. The information presented on the screen was somewhat different in that mode. The subject was given information about the current location of the cursor in Hz ("Current Position: xx ") and the number of responses made so far in the current trial and the last frequency clicked on ("Frequency of line n is xx Hz"). This information appeared at the bottom of the screen in the standard configuration and the left hand side of the screen in the display rotated configuration, The instructions 'Identify All Lines Visible on Screen' and 'PRESS F1 WHEN COMPLETED' were also presented in this area.

In both modes, the initial noise background was generated in advance and stored in an image file that the controlling software read in at the beginning of a run. For the static mode, the noise distribution of the first band was divided into four sections at the start of a run and then randomly recombined to create four new bands for every trial. This was done because regeneration of the complete display required too much time and computer memory to be done within the application. Signal lines extended the total number of time bins of each FTI display. In the dynamic mode, the background image file was updated at regular intervals. Updating involved deleting the top (rightmost) line of pixels on each of the four bands, shifting the remaining lines up (right) one pixel, and adding a new line of signal and noise background pixels to the bottom (left) of each band. Thus, signal lines appeared initially at the bottom (left) of a frequency band and increased in length until they reached their maximum duration. They then slowly disappeared off the top (right) of the band.

In the static mode, subjects were told how many responses they had made so far in the trial, but they had to remember which ones they had detected. Since the number of signals on the display in the dynamic mode at any one time was relatively large in this experiment, it would have been extremely difficult for the subject to keep track of which signals he or she had detected. Thus, all frequency bins marked by the subject were annotated with either a "^" and/or a "*" at the top (right on the rotated display) of the appropriate band. When a subject first marked a frequency bin, the "^" symbol appeared at the top of that line of pixels. If the subject marked a signal a second time (usually because they thought there was a doublet), the "*" symbol was placed above the bin marked. Each symbol was removed when the corresponding signal line disappeared off the screen[2].

Each pixel on the display was mapped onto one of eight different luminance levels (Table 1). This mapping corresponded to quantizing the intensity of the incoming sound into eight levels. Previous research(9, 10) has shown that detection of lines on an FTI display is not improved by using more than eight quantization levels. The sets of luminances for the two monitors in the main study and the long cable condition were nominally the

[2]Symbols were added above every frequency bin that the subject marked. However since the criterion for removing a symbol was the disappearance of the associated signal off the display, only the symbols that marked actual signals could be removed. Symbols resulting from false alarms remained on the display for the duration of the run.

same with each luminance level being approximately $2\sqrt{2}$ times the next lower level[3]. However, as shown in Table 1, there was some variation in the actual luminances that were achieved. This was due in part to day to day variation and in part to the fact that only 64 DAC levels were available. The values for the low luminance condition reflect the drop in luminance of the monochrome monitor over a four month period.

Table 1: Average pixel luminances used in the current experiment[4].

Condition	Monitor	Luminance levels (cd/m^2)							
		1	2	3	4	5	6	7	8
Main study	Monochrome	<0.01	0.06	0.20	0.53	1.4	4.1	10.9	32.3
	Multichrome	<0.01	0.07	0.19	0.60	1.6	4.5	11.9	32.3
Long cable	Monochrome	<0.01	0.06	0.19	0.5	1.4	4.1	11.5	31.7
Low luminance	Monochrome	<0.01	0.01	0.06	0.20	0.89	2.8	9.0	26.9
	Multichrome	<0.01	0.02	0.07	0.26	0.98	2.8	9.8	26.7

Stimuli

The stimulus set used in the experiment consisted of 180 frequencies evenly distributed across the four bands at each of six intensities (total = 1080). Signals could be either single lines or members of a doublet. Single line signals were defined as signals that were at least 2 Hz from another signal on the three lower frequency bands and 3 Hz from another signal on the highest frequency band. Doublets were two signals 1 Hz apart on the three lower frequency bands and 2 Hz apart on the high frequency band. This meant that doublets were separated by three pixels on the two lower frequency bands and one pixel on the higher frequency bands[5]. Members of doublets were further defined as being high intensity or low intensity (even if both members had the same intensity). Approximately 70% of the signals were single lines. The remaining 30% were one member of a doublet. All signal lines had a maximum length of 112 pixels (the number of time bins in each band), were one pixel wide, and were fixed in frequency (were straight lines) and average intensity over time.

For each signal in a stimulus file, the frequency was randomly selected without replacement from the population of 180. Next one of the six signal intensities to be used in that run was randomly selected. Finally, the signal type, single or doublet, was randomly selected such that 70% of the signals were single lines. If a line was selected to be a doublet, the frequency of the next signal would automatically be 1 Hz higher or lower than the

[3]The one exception to this was the luminance of the lowest level pixel which was always set to DAC value 0 or the background level of the monitor.
[4]Since the lowest value that the colorimeter displayed was 0.01 cd/m^2, luminances below that level could not be measured. An initial calibration with an EG&G spectroradiometer indicated that the background luminances (and the luminances of level 1) of both monitors were around 0.001 cd/m^2.
[5]Because of a limitation in the simulation, signals on the display had to be at least 1 Hz apart.

previous signal (2 Hz on the highest frequency band). Its intensity would then be randomly selected. The member of that doublet with the higher intensity would be of type higher intensity doublet and the other would be of type lower intensity doublet.

Signal lines were presented against a Gaussian noise background. The distribution of luminances for both the noise background and the signal intensities were generated using equation 1 for the binomial rule(10). In this equation, p is the mean of the distribution (0-1), i is the specified level (1-8), N is one less than the number of levels being used (in this case 7), and $r = i - 1$. By varying the p value one varies the probability that a specific luminance level is assigned to a specific pixel. To create a Gaussian noise background, p is set equal to 0.5. To generate signals that would be discriminable from the background noise and on average brighter than the background noise, p values greater than 0.5 were used. As the p value increases from 0.5 to 1, the distribution of luminances will be skewed increasingly towards the higher levels and hence a set of pixels (a signal line) will be increasingly discriminable from a background noise with a p of 0.5. Based on pilot tests, a set of probability distributions or p values were selected that would result in signals whose detectability ranged from less than 10% to close to 100% (Table 2). A slightly higher range was used for the training runs to provide subjects with more examples of signals during the training runs.

$$P(i) = \frac{N!}{r!(N-r)!} \times p^r (1-p)^{N-r} \qquad (1)$$

The mean luminance of the noise background and the signals was calculated numerically using equation 2 (10). p_i is the probability that the luminance level L_i will be assigned to a pixel. Using this equation, it was calculated that the average background luminances were 2.1 and 2.3 cd/m^2 for the monochrome and multichrome monitors respectively in the main study, 1.5 and 1.6 cd/m^2 for the same monitors in the degraded luminance conditions and 2.1 cd/m^2 for the monochrome monitor in the long cable condition. The mean luminances of the sets of signal lines used throughout the experiment are shown in Table 2. The corresponding signal intensities in dB are also shown. Since the p values represent the cumulative probability of the normal distribution, the signal intensity for each p value in dB is 20×log10 of the z value that corresponds to that probability.

$$\bar{L} = \sum_{i=1}^{i=N} p_i L_i \qquad (2)$$

Table 2: Probability distribution, strength and mean luminance of each signal used in the training and test sessions.

Static Training						
Probability (p)	0.62	0.64	0.66	0.68	0.70	0.72
Signal Level (dB)	-10.5	-8.9	-7.7	-6.6	-5.5	-4.7
Monochrome luminance (cd/m^2)	4.4	5.0	5.6	6.3	7.0	7.9
Multichrome luminance (cd/m^2)	4.8	5.3	6.0	6.7	7.5	8.3
Dynamic Training						
Probability (p)	0.60	0.62	0.64	0.66	0.68	0.70
Signal Level (dB)	-12.0	-10.5	-8.9	-7.7	-6.6	-5.5
Monochrome luminance (cd/m^2)	3.9	4.4	5.0	5.6	6.3	7.0
Multichrome luminance (cd/m^2)	4.2	4.8	5.3	6.0	6.7	7.5
Testing						
Probability (p)	0.59	0.61	0.63	0.66	0.68	0.70
Signal level (dB)	-12.7	-11.1	-9.6	-7.7	-6.6	-5.5
Monochrome luminance (cd/m^2)	3.7	4.2	4.7	5.6	6.3	7.0
Multichrome luminance (cd/m^2)	4.0	4.5	5.0	6.0	6.7	7.5
Low level monochrome (cd/m^2)	2.8	3.2	3.6	4.4	4.9	5.6
Low level multichrome (cd/m^2)	2.9	3.3	3.8	4.6	5.1	5.8
Long cable monochrome (cd/m^2)	3.7	4.2	4.8	5.7	6.3	7.1

Conditions

The main experiment compared detection performance in the standard and display-rotated format on both the monochrome and multichrome monitors. Twelve subjects carried out this experiment. Six subjects used the standard display format on each of their runs and six used the display rotated format. Half of the subjects in each format started on the monochrome monitor and the other half started on the multichrome monitor. Each subject completed 5 training runs followed by eight test runs in the main experiment. Four of the test runs were carried out on each monitor.

After completing the main experiment, half of the subjects in each display format carried out four additional runs using the low luminance table (Table 1). This table simulated the degradation in brightness of the monitor over time. The remaining six subjects, three in each format condition, carried out four additional runs on the monochrome monitor with the long cables in place.

Task

The task was to detect the signal lines that appeared on the FTI display. The subjects indicated the location of each signal by using a mouse to position the line cursor on top of what they perceived to be a signal and then pressing the left mouse button. They were allowed a leeway on either side of the signals of ±1 Hz on the three lower frequency bands and ±2 Hz on the highest frequency band. Subjects were informed that they were not expected to detect all the signals and that they were to maximize correct detections while minimizing missed signals and false alarms. In the static mode (used in the first three training sessions), 6 to 10 signal lines appeared on each trial. When the subjects felt they had detected all the signals that they could see on that particular trial, they pressed 'F1' to advance to the next trial. In the dynamic task, subjects continuously identified new lines as they appeared on the screen over a 35 minute period.

Procedure

Before giving informed consent, participants read a protocol that provided some background on the purpose of the study, an explanation of the task, the experimental conditions, and the risks. Once consent had been given, subjects were administered a visual acuity test, using a Regan chart at a distance of 6.1 m, and a contrast sensitivity test, using a two alternative forced choice task controlled by a Nicolet Optronics CS2000 Contrast Sensitivity System(11). Since the task involved the detection of near threshold signals, we wanted to be certain that subjects had normal contrast sensitivity as well as normal or corrected to normal visual acuity.

Each subject completed 17 runs over 8 sessions - two training sessions followed by six test sessions. Sessions lasted approximately one and a half hours including breaks and were carried out on separate days. During the runs, subjects were seated in an adjustable chair at a distance of approximately 53 cm from the screen in a dimly lit room. Other than the screen itself, the only illumination was from an incandescent pot light located above the monitor. The light was adjusted so that approximately 0.5 lx fell on the screen and 3 lx fell on the keyboard[6]. The task was carried out under low ambient illumination to maximize contrast on the screen.

The first training session used the static mode, the second the dynamic. At the start of each training session, the task was demonstrated to the subjects and they were given a chance to practice it. For the static training session, they were told that between 6 and 10 signal lines would be presented on each trial, that each signal line would be the full height (width) of a band, that they had the leeway specified above in marking a line, and that they should identify both members of a doublet.

After the demonstration of the static mode, subjects completed three training runs. On the first training run, subjects were given a list stating the frequency, type, and intensity of each signal presented on each trial of that run. With this information, subjects could see what different types and intensities of signals looked like and what percentage of the signals they were likely to see on a trial. On all three runs feedback was provided in the form of a beep after each correct detection. The first run was 15 trials and the other two runs were 30 trials. All three runs were complete on the same monitor in a single day. Subjects were given breaks between runs.

For the dynamic training session, subjects completed two runs of 35 minutes each with an extended break between runs. Initially, there were no lines on the display. A new signal line was added every ten seconds (for a total of 210 lines per run) and the display was

[6] All ambient lighting conditions were measured with a Hagner Universal Photometer in the illumination mode.

updated at five second intervals. During the first run subjects were provided with a list of the frequency, type, and intensity of the first 90 signal lines that appeared on the screen. The subjects were told that there were no lines on the display at the beginning of the run, that signal lines would be added at regular intervals at the bottom of the screen and would gradually move up the screen (the signal lines would get longer over time), and that every time they clicked on a frequency that position would be marked with a "^" or a "*". The first time they clicked on a location, a "^" would appear at the top of that FTI display at that location. If they clicked on the same location twice or on a location within the error margin for a marked location a "*" would be placed at the top of that position. These marks were to help them keep track of the signal lines that they had already identified. No feedback was given. To avoid errors due to multiple button pushes, button pushes within one second of the most recently recorded response were not counted.

Before each subject moved on to the test portion of the experiment, a brief analysis was done to check if their performance was likely to fall within the range of test signal strengths and if their false alarm rate was excessively high. If they had more than 20 false alarms in a run, they were encouraged to use a more conservative decision criterion.

Following training, each subject completed six test sessions of two runs each. The test runs were identical to the dynamic training runs except that a different set of probability distributions and stimulus files were used. The same set of four stimulus files were used on each monitor, but the order that the stimulus files were presented in was randomized for each condition and subject.

The main experiment with the standard video cable and luminance table were carried out during the first four tests sessions. The first and third session were carried out on one monitor and the second and fourth on the alternate monitor. During the remaining two sessions, six subjects completed four runs (two on each monitor) using the "degraded luminance" levels and six subjects completed four runs with the long cables in place on the monochrome monitor. In both cases, half of the subjects were in the display rotated condition and half were in the standard condition.

RESULTS

Dependent measures

The results from a pilot study indicated that signals that were initiated less than five minutes before a run ended were unlikely to be detected. Thus, it was decided to make the runs 35 minutes in duration, but to include only the data for signals initiated in the first thirty minutes of a run in the analyses.

The percentage of correct detections for each type of signal, false alarms, and response times were calculated overall and as a function of time on task. Since the number of signals on the display varied as a function of time and subjects could make as many as 2100 responses during a session, it was difficult to specify the total possible number of false alarms. Thus, false alarm rate was specified as the number of false alarms per session. Response times were recorded in terms of number of updates. Response times in seconds can be determined by multiplying the number of updates by 5.

As well, the percentage of correct hits at each signal strength was calculated and percent correct as a function of signal strength determined using the Probit routine in SAS®(12). These functions were determined for all types of signals and separately for single line signals, high intensity doublet lines, and low intensity doublet lines. From this analysis, the signal strengths at which the subjects detected 25%, 50%, and 75% of the signals were determined.

Display orientation and monitor type

Table 3 shows the percentage of signal lines detected over all and by type, the number of false alarms per run and the average number of updates before a line was detected for each combination of monitor type and display rotation. As can be seen, the results are essentially the same for the two types of monitors with each display type. The exception is the number of false alarms per run for the rotated display. However, that difference was due almost entirely to one subject who had an extremely high false alarm rate on the first two runs because of a large number of responses right at the beginning. Once reminded that there were no signals at the beginning of the run the subject's scores fell in line with the other subjects. An analysis of variance indicated that there were no significant differences between the two types of monitors on any of the performance measures listed in Table 3.

Table 3: Average performance on each of the dependent measures for each condition.

Performance Measures	Conditions			
	monochrome		multichrome	
	standard	rotated	standard	rotated
% Hits overall	47.4	59.1	47.6	59.0
% Hits T0	49.5	59.8	50.0	60.4
% Hits T1	61.5	73.5	61.8	73.9
% hits T2	23.5	41.5	21.9	37.7
False alarms per run	17.3	25.7	18.8	17.0
Number of updates	67.7	59.8	68.4	60.9

T0 = single lines; T1 = higher intensity doublet lines; T2 = Lower intensity doublet lines.

On the other hand, as shown in Table 3, there were noticeable differences between the two display orientations for each monitor type on most of the performance measures. A repeated measures analysis of variance was carried out to determine if these differences in performance were significant. Since there were no significant differences as a function of monitor type and no significant interaction between monitor type and orientation, the data were collapsed across monitor type. The results of the analysis indicated a significant difference between the two orientations for all signal types together ($F(1,10)= 7.2$, $p < 0.05$), single lines ($F(1,10) = 8.1$, $p < 0.05$), higher intensity doublet lines ($F(1,10) = 5.2$, $p < 0.05$), and for number of updates ($F(1,10) = 5.3$, $p < 0.05$). The similarity in number of false alarms with the two display formats indicates that differences in hit rate were due to differences in sensitivity rather than to a criterion shift(13).

Figure 2 shows the average signal strengths leading to 25%, 50%, and 75% hit rate in the standard and display rotated formats on each type of monitor for all signal lines and for each type of signal line. The largest differences were found with the lower intensity doublet lines where there was about 2 dB difference between the standard and rotated condition. For all other types of signals, there was about 1 dB difference between the standard and the rotated condition. An analysis of variance was carried out on the differences in performance between the two formats at the 25%, 50%, and 75% hit rates. Again the data for the different monitor types were pooled. The difference between the two formats was significant ($p < 0.05$) at all hit rates and for all signal types except for higher intensity doublet lines at the 25% hit rate.

Performance over time was measured to assess the effect of time on task and screen clutter. Figure 3 shows the number of hits and number of updates as function of time on task. The number of signal lines increased from one at the start of the run to a maximum of 112 at about the nineteen minute point. From that time on, the number of signal lines was stable. This pattern is reflected somewhat in the performance measures. The number of hits per five minute interval increased as the number of signal lines increased. However, after about the first 10 minutes, the number of hits tended to level off at about 15 signal lines per five minute interval with the standard format and 19 signal lines for the rotated format. The number of updates required for detection also increased rapidly at first and then levelled off somewhat as the number of signal lines levelled off.

Although there was no significant difference in false alarms per run between the two formats there was a considerable difference across subjects. According to signal detection theory, detection or hit rate should increase as false alarm rate increases. To get a picture of the relationship between hits and false alarms, the percentage of lines detected in a run was plotted against the number of false alarms for that run for each run carried out on each display format (Figure 4). As expected, percentage of signal lines detected did increase as a function of number of false alarm. However, signal detection was always higher in the rotated display condition at all false alarm rates.

Degraded display conditions

Subjects' performance in the low luminance condition was compared with their last four runs (two on each monitor) using the standard luminance table. As can be seen in Table 4 and Figure 5, performance was essentially similar under the two luminance conditions on both types of monitors and with both display formats. The results for the long cable condition were less clear. The results in Table 5 and Figure 6 indicated a small but positive improvement in hit rate with the long cable. However, a repeated measures analysis of variance showed no significant difference as a function of cable length or as a function of display format.

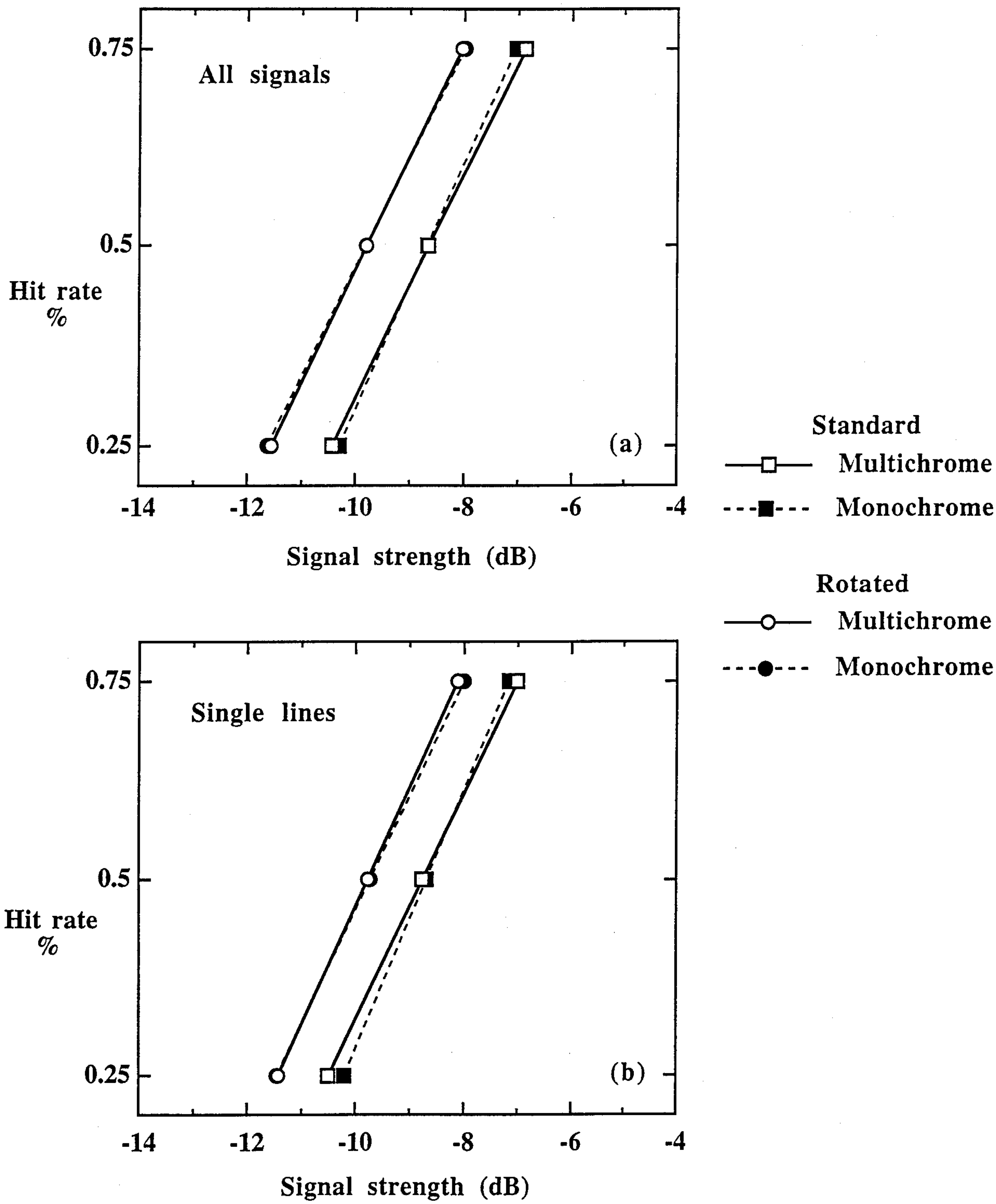

Figure 2: Signal strength leading to 25%, 50%, and 75% hit rates as a function of display orientation and monitor type for all types of signal lines (a) and for single lines (b).

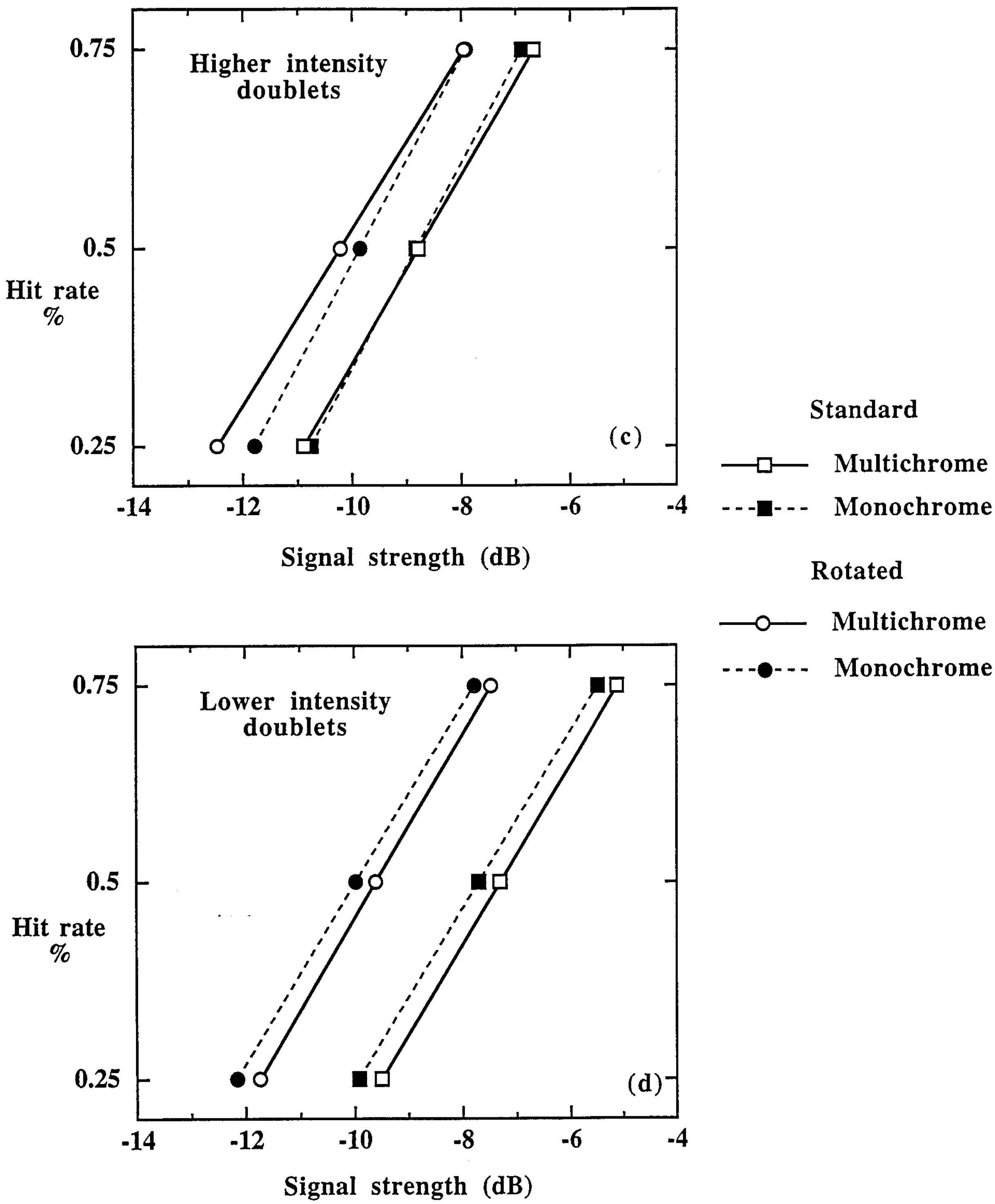

Figure 2 cont.: Signal strengths leading to 25%, 50%, and 75% hit rates as a function of display orientation and monitor type for higher (c) and lower (d) intensity doublet lines.

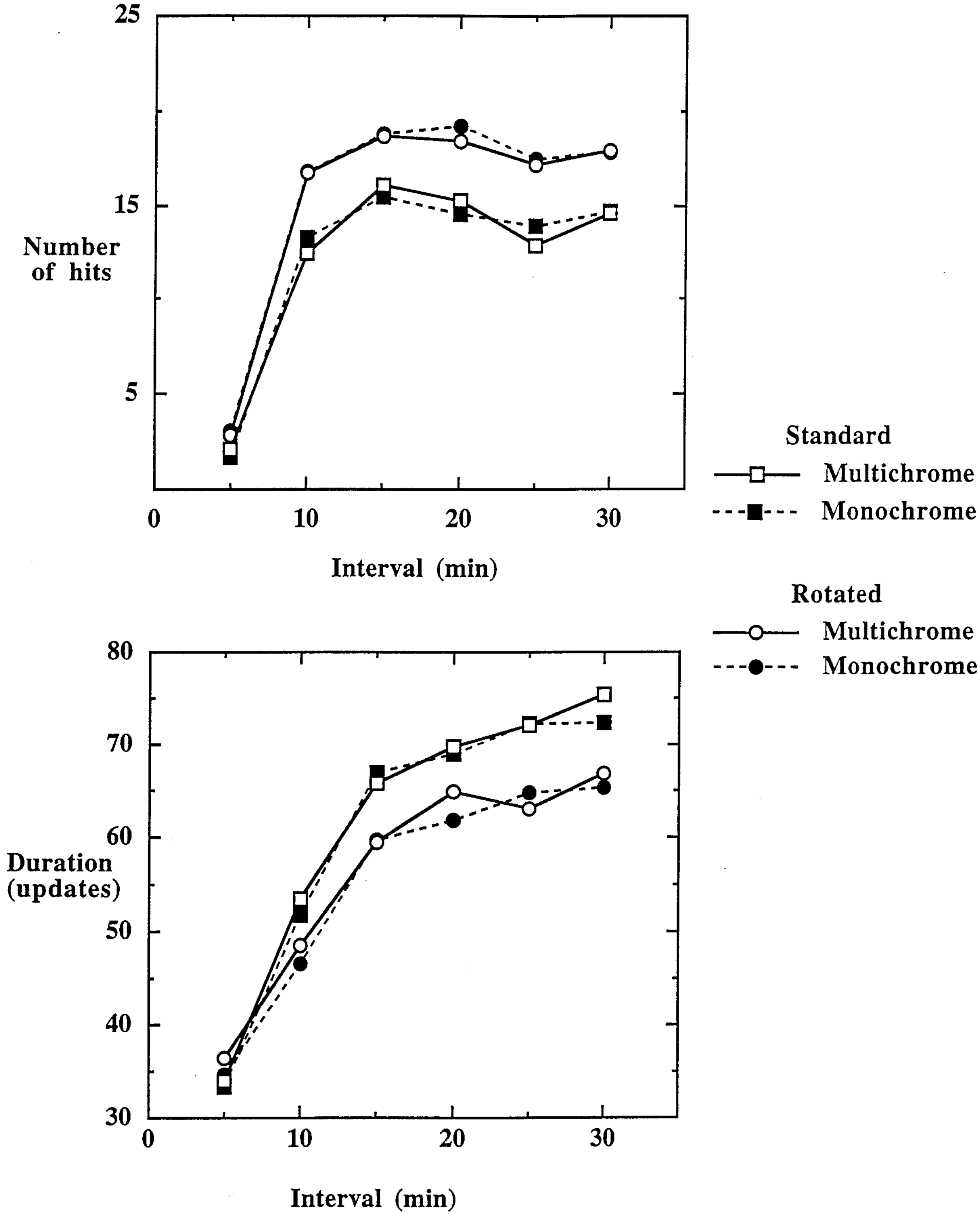

Figure 3: Average number of hits (a) and average duration of signal lines when detected (b) in each successive five minute interval across the 30 minute run.

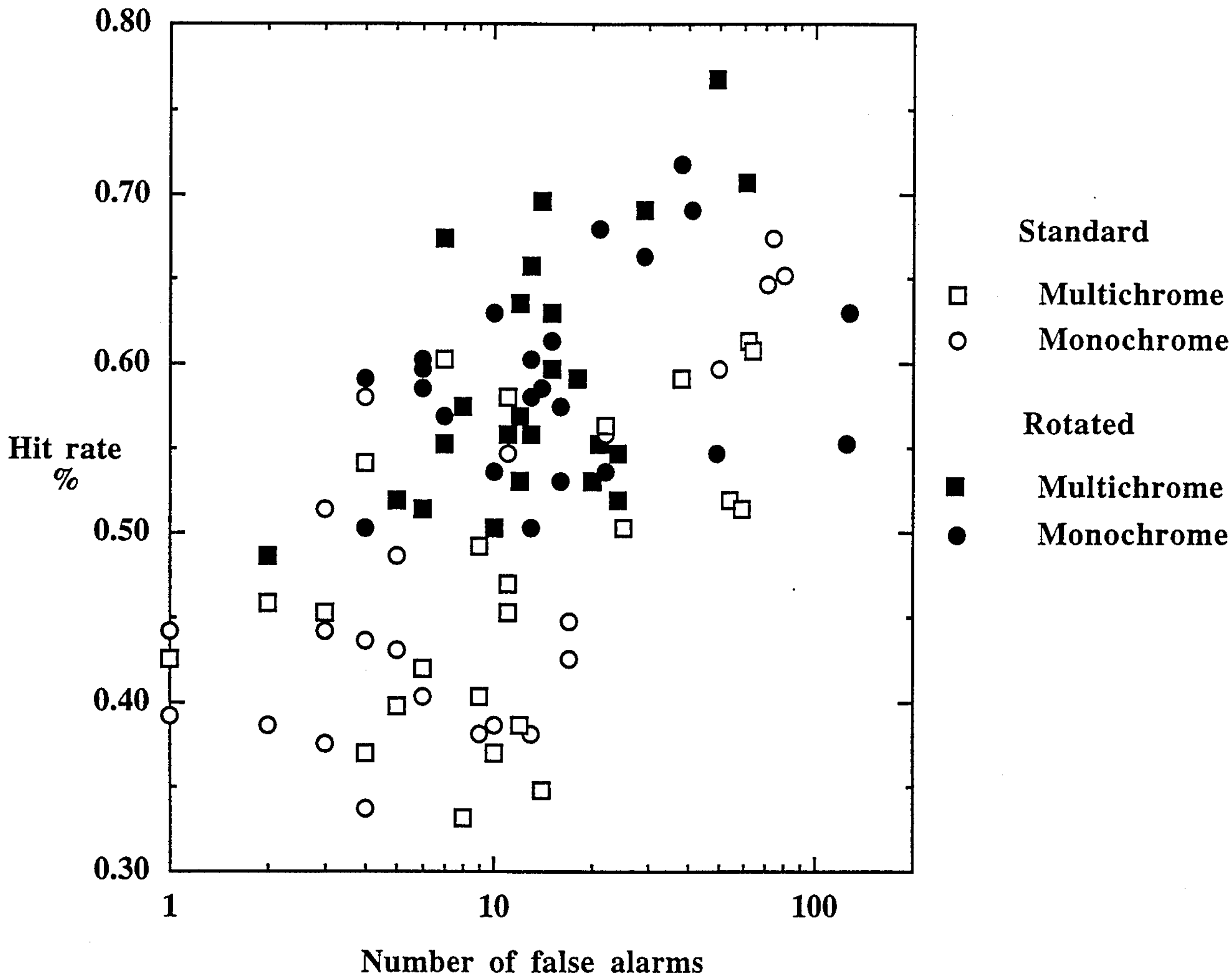

Figure 4: Hit rate on each run as a function of the number of false alarms in that run.

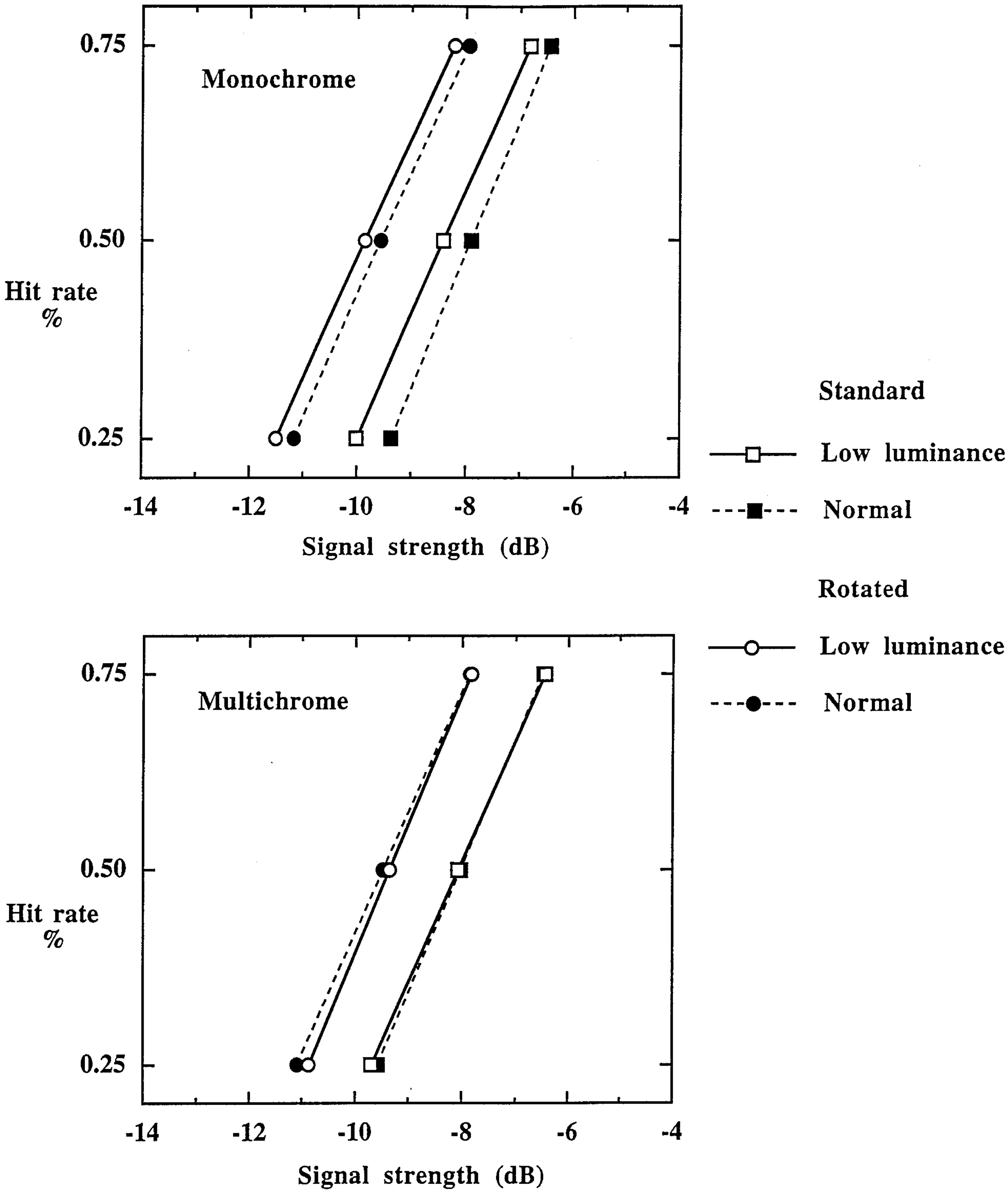

Figure 5: Signal strength leading to 25%, 50%, and 75% hit rates on the monochrome and multichrome monitors as a function of the set of luminance values used to code intensity.

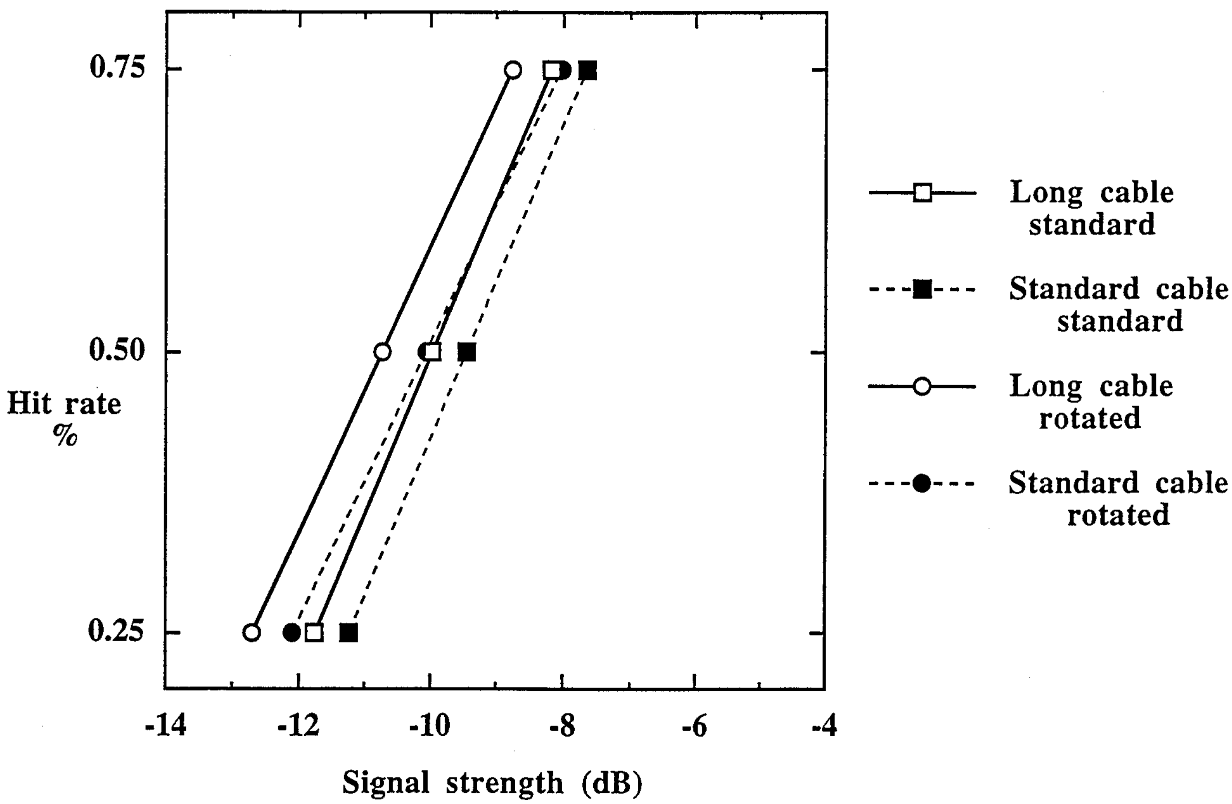

Figure 6: Signal strength leading to 25%, 50%, and 75% hit rates on the monochrome monitor as a function of type of video cable used.

Table 4: Average performance on each of the dependent measures in the degraded luminance condition.

Performance Measures	Standard				Low luminance			
	monochrome		multichrome		monochrome		multichrome	
	standard	rotated	standard	rotated	standard	rotated	standard	rotated
Percent hits	39.0	58.6	41.2	57.3	45.5	59.7	42.1	54.9
Percent hits T0	42.5	59.1	44.7	58.1	48.0	60.6	44.4	56.6
Percent hits T1	48.9	73.6	53.4	73.2	62.0	77.3	56.6	72.8
Percent hits T2	12.0	41.3	12.6	37.6	17.2	37.8	16.6	28.9
False alarms per run	6.0	10.2	7.8	8.5	5.2	14.0	6.5	8.2
Number of updates	64.0	58.4	68.2	58.0	66.4	59.9	67.1	59.6

Table 5: Average performance on each of the dependent measures in the long cable condition.

Performance Measures	Standard		Long Cable	
	standard	rotated	standard	rotated
Percent hits	55.0	61.1	60.6	67.1
Percent hits T0	55.5	61.9	62.7	69.2
Percent hits T1	72.8	75.3	77.1	80.1
Percent hits T2	34.4	42.9	34.5	44.6
False alarms per run	16.6	26.8	13.9	15.8
Number of updates	67.0	60.9	60.2	58.8

DISCUSSION

It had been hypothesized that the Resolution to Addressability Ratio (RAR) of the shadow mask CRT would have a deleterious effect on detection of signal lines especially doublet lines on a passive sonar display. However, the results of a previous study(5) indicated that performance on a passive sonar display is not likely to be affected by the difference in RAR of current generation monochrome and multichrome monitors. As discussed in the report on that study(5), detection thresholds are more likely determined by factors such as pixel width and frequency range. Although the shadow mask did not interfere with detection of signals on a standard format FTI display, there was still the possibility that it would impair the improvement in visibility associated with having the signal lines fall along the scan lines of the CRT that has been found with a monochrome CRT. As well, the lower resolution of the multichrome monitor might lead to increased fatigue and concomitant reduction in performance over time. Thus, the current study was run to assess the effect of having signal lines fall along the scan lines of a multichrome monitor. As can be seen in Table 3 and Figure 2, hit rate and response rate were essentially identical on both monitors independent of display format. As well, there was no differential degradation in either hit rate or response rate over time between the two types of monitors (Figure 3). Thus, it would seem that any improvement in performance due to using a rotated display format will be realized on either type of monitor.

The current study used a dynamic mode in which signals were added to the bottom of the display and increased in length over time as the display was updated. It was thought that the dynamic mode would allow us to assess performance over time better. The actual improvement in hit rate that occurred when the FTI display was configured so that signal lines fell along the scan lines rather than perpendicular to them was noticeably greater than in a study in which subjects were presented with a known number of signal lines on a static display(5). Most of the improvement with the rotated display format in that study was found in the detection of the lower intensity member of line pairs and in the detection of lines that were detected about 50 to 60% of the time on the standard format display. With the dynamic mode, signal lines were detected sooner and at lower signal strengths on the rotated format relative to the standard format. In both studies, the largest improvement was found with the detection of the lower intensity member of line pairs. However, there was also a 1 dB improvement in the detection of single lines at 25%, 50%, and 75% detection rates. These results suggest that there could be a considerable benefit to using a display format in which signal lines fall along the scan lines of the CRT.

It is not clear if the greater difference in hit rate and response rate between the rotated and standard formats in the current study was due to the use of a dynamic mode or to the increased clutter. If the larger difference in performance was due to clutter then one would have expected the difference to increase up until about the 20 minute point. However, it levels out at about the 10 minute point or at about the time the first signal lines reach their maximum length. The improvement in detection over the first ten minutes probably reflects the improvement in detectability that occurs with increasing line length. Thus the greater effect of display format found in this study is probably due to the use of the dynamic mode.

The improvements in performance with the rotated FTI display have all been found with naive subjects. None of the subjects had any prior experience with a passive sonar system. If the format of an operational system were modified so that signal lines fell along the scan lines of the CRT, the same advantage might not occur. Operators have had extensive experience with the current display layout. As stated in the introduction, successful target recognition is thought to involve matching the pattern on the screen with an internal template that has been built up as a result of extensive experience with similar patterns. There might be considerable negative transfer if substantial changes were made to the display format. In the previous studies that examined detection and classification of targets on the standard and display rotated formats, subjects carried out a final set of runs on a different orientation than they had been trained on. Performance was not adversely affected when they switched from one format to the other, but they had only had a few hours exposure to the initial orientation. To reduce negative transfer of training, it would seem preferable to rotate the monitor rather than the FTI display itself. In a previous study that looked at detection of signal lines with all three formats (standard, display rotated, and monitor rotated), there was no difference in the detectability of lines on the display rotated and the monitor rotated format. However, changing the orientation of the monitors could necessitate a redesign of the display screens. Thus, before such a redesign is undertaken, it would seem beneficial to to run a field study to assess the impact of rotating the FTI display on the performance of experienced operators.

Degraded display conditions

In the laboratory, computer systems are carefully maintained to ensure that performance levels and differences in performance over time are due to the parameters under study and not to extraneous factors. In operational conditions, such control is not possible. Moreover, operational constraints may result in the operator having to use a less than optimum system. The degraded luminance and long cable condition attempted to assess the impact of moderate degradation on detection of signals on a FTI display.

The 20% reduction in luminance that was employed in this study, did not subjectively affect the appearance of the FTI display. The impact on detection of signals was also negligible. The scores of the three subjects that carried out this condition was similar to their performance with the standard luminance.

The effect of the long cables was to reduce the contrast of the monitor perceptibly and in some cases to create a double image. It was expected that performance on the detection task would be degraded when the long cables were used, especially with the standard display format. However, the impact on hit rate was, if anything, positive. Hit rate improved somewhat with both display orientations. Since the long cable runs were completed after the standard cable runs, it is possible that the improvement was due to experience with the task. Figure 7 tends to support this hypothesis. As can be seen, there is a small but steady improvement in hit rate across runs for the subjects that participated in the long cable condition. Interestingly, the subjects in the low luminance condition did not show a similar improvement over time.

Overall, moderate changes in the monitor characteristics appear unlikely to impact significantly on the detection of signals on an FTI display. This does not mean that these factors can be ignored. There is a substantial literature on the impact of image quality of visual display units on fatigue and performance. Every effort should be made to optimize the display presented to the operator. One such method for maintaining calibration is to provide the operator with a display composed of eight rectangles each at one of the luminance levels at which the pixels are presented. The operator could adjust the brightness and contrast controls so that each successive luminance level is discriminable from the luminance levels on either side under the ambient illumination conditions in which the monitor will be used. If the monitor cannot be adjusted to meet this criterion, it should be recalibrated using a photometer.

Static versus dynamic mode

A wide range of methodologies are potentially available for assessing sonar system performance. Ideally, one wishes to be able to determine the impact of a particular parameter on operational performance in the most efficient manner possible. With the static mode used in the previous detection study(5), it typically took 10 to 15 minutes to complete a run during which the observer was presented with approximately 180 signals. With the dynamic mode in this study, it took 30 minutes to present the same number of signals and

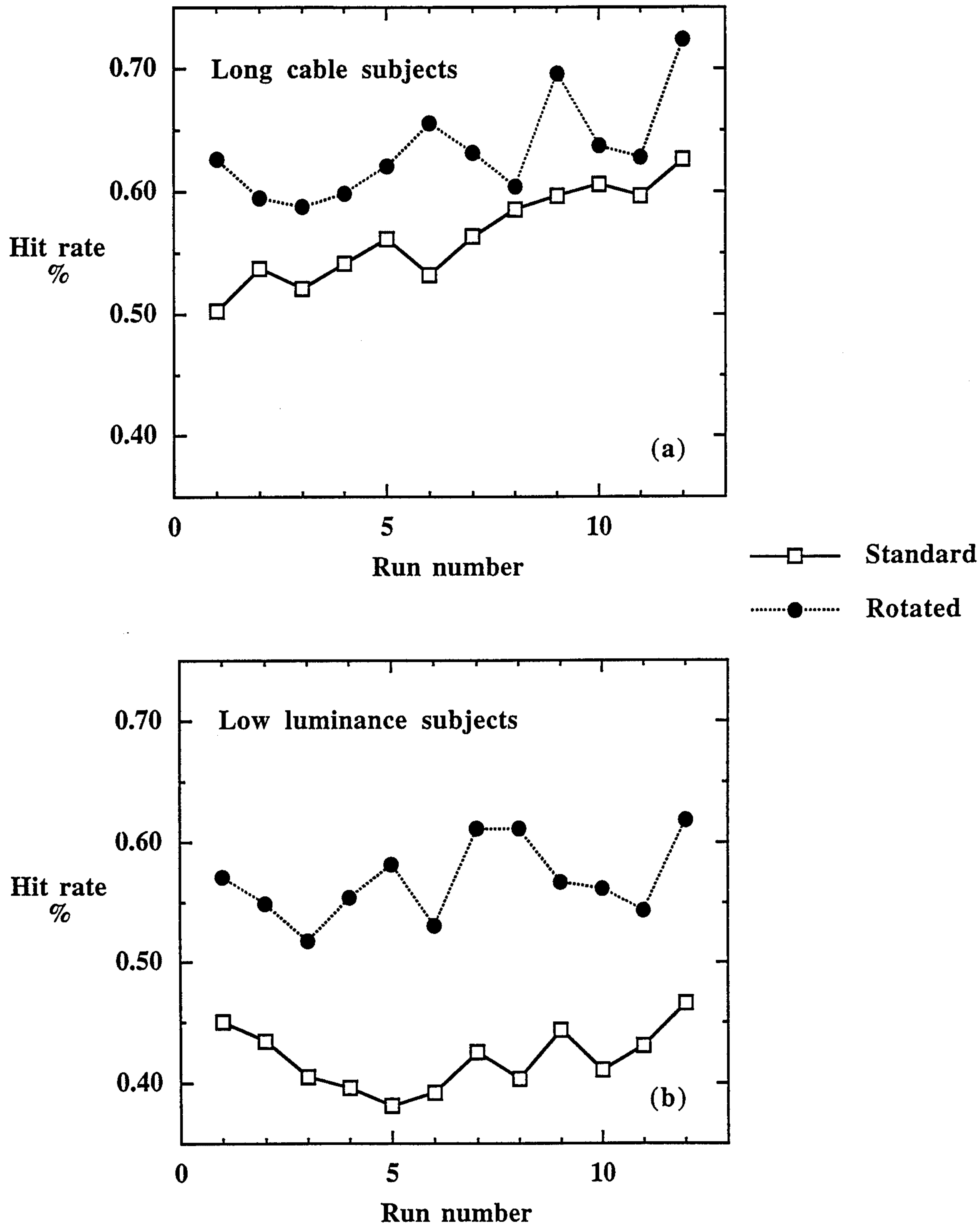

Figure 7: Hit rate as a function of run number in the standard and rotated conditions averaged across the subjects that carried out the long cable condition (a) and the subjects that carried out the low luminance condition (b).

presenting such a large number meant that the display was very cluttered for a large portion of the run. The use of discrete trials in the static mode meant that subjects were presented with a fresh image at regular intervals. This tends to keep the subject more alert. With the dynamic mode, the display changed relatively slowly over time. There was no dramatic change to stimulate the subjects. The use of a fixed number of signals in the static mode meant that subjects tended to mark a certain number of lines and then to move on to the next trial. The effect of this was that false alarms per trial tended to be relatively low (around one per trial). Fatigue, boredom, and variations in false alarm rate can lead to increased variability across runs and subjects which could mask differences due to the parameter under study. Thus, the static method would appear to be a reasonably efficient and effective method of measuring performance.

On the other hand, the fact that a similar number of signals were presented on each trial and all signals extended across all time bins meant that the subjects quickly gained a reasonable concept of what constituted a signal and a non-signal event. With the dynamic mode, signals appeared on the screen gradually and subjects did not have as clear a picture of what constituted a signal at any point in time. The impact of this difference in these studies was that the benefit of the rotated display format on hit rate and response rate was much less evident with the static mode. Moreover, it is not clear that reducing the effects of observer criterion, fatigue, and boredom is necessarily a good thing. These effects do occur in the operational situation and it is important to understand how display parameters affect them and vice versa. Overall, one must be careful that the method used does not mask the real effects of the characteristics under study.

CONCLUSIONS

An experiment was carried out to examine the detectability of signals on an FTI display on a monochrome and multichrome monitor when the standard FTI display format was used and when the display was rotated so that time was along the x axis and frequency along the y axis. The latter format meant that signal lines fell along the scan lines of the CRT. Performance as measured by hit rate and response rate, was significantly better with the rotated display format than with the standard format on both the monochrome and multichrome monitors. There was no difference in performance as a function of monitor type. Degrading the display by introducing a long video cable or by reducing the average luminance by 20% did not adversely affect performance with either format. Thus, based on the findings of the previous and current studies, the use of multichrome monitors are not like to degrade detection of lines on FTI displays and having signal lines fall along the scan lines of the CRT should improve their visibility. The benefit of increased visibility is that lines are detected sooner and at a lower signal strength.

RECOMMENDATIONS

1) Serious consideration should be given to either modifying the orientation of the FTI display or rotating the monitor so that signal lines fall along the scan lines of the CRT.

2) A field study should be run to assess the impact of reorienting the FTI display on the performance of actual operators.

3) Future studies aimed at assessing the impact of display or other parameters on operator performance on a passive sonar display should employ a simulation that allow the assessment of performance over time and in which the operators knowledge of the signals is low.

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With current sonar technology the operator must handle large quantities of data. The primary medium for displaying this data is the CRT. Because of the limited space available on the CRT, the operator must scan multiple pages of data rapidly if he or she is to monitor all of the information. Thus, signal visibility is critical. To ensure good visibility, it is necessary to understand the impact of display characteristics on the detectability of signals on a display. This study examined two factors that could influence the detection of lines on a frequency-time-intensity (FTI) display. The first was type of monitor - multichrome or monochrome. Current systems use a monochrome monitor because its resolution is believed to be superior to a multichrome monitor. The second was orientation of the signals relative to the orientation of the CRT raster. Currently, the signals on an FTI display are perpendicular to the CRT raster. The study examined the advantage of having signal lines on the FTI display fall along the scan lines of the CRT. In addition, performance was assessed in two conditions in which the visual image was potentially degraded. The degraded displays resulted from the reduction in average luminance of the monitor that frequently happens over time and the use of long video cables between the computer monitor and processor. In all the conditions, subjects had to detect signals of varying strength presented on a simulated FTI display. Signals were added to an FTI display that was updated every 5 seconds. Performance was similar on the monochrome and multichrome monitors. However, there was a clear advantage, on both types of monitors, to using a display format in which the signals fell along the scan lines of the CRT. Between 12 and 18% more signal lines were detected on the rotated display format as compared to the standard format. Degradation of the output had no perceptible effect on detection of the signal lines. It was concluded that detection is not impaired on a multichrome display and that there is an advantage to designing the interface for a passive sonar display so that the signals fall along the scan lines of the CRT.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible, keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and the thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

passive sonar
detection
visibility
resolution
monochrome
multichrome
display
orientation
methodology